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ORIGINAL ARTICLE

Performance analysis of IMS based LTE and WIMAX integration architectures

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Abstract In the current networking field many research works are going on regarding the integration of different wireless technologies, with the aim of providing uninterrupted connectivity to the user anywhere, with high data rates due to increased demand. However, the number of objects like smart devices, industrial machines, smart homes, connected by wireless interface is dramatically increasing due to the evolution of cloud computing and internet of things technology. This Paper begins with the challenges involved in such integrations and then explains the role of different couplings and different architectures. This paper also gives further improvement in the LTE and Wimax integration architectures to provide seamless vertical handover and flexible quality of service for supporting voice, video, multimedia services over IP network and mobility management with the help of IMS networks. Evaluation of various parameters like handover delay, cost of signalling, packet loss,, is done and the performance of the interworking architecture is analysed from the simulation results. Finally, it concludes that the cross layer scenario is better than the non cross layer scenario.

1. Introduction

In the current networking field due to increased demand, many research works are going on regarding the integration of different wireless technologies with the aim of providing uninterrupted connectivity to the user anywhere, with high data rates. Network convergence is regarded as a major challenge in the evolution of tele and computer communications. To provide users with voice, video, data and multimedia services at high speeds and cheaper rates, two technologies were developed. They are LTE and WIMAX.

1.1. WIMAX

WIMAX: It is expanded as worldwide inter-operability for microwave access. It belongs to the family of IEEE 802.16 wireless access network standards. Mobile broadband access in cities can also be provided by Wimax. Simply put, it is the Improvisation of WLAN to WAN and MAN. It has a coverage range up to 50 km, which is helpful in NLOS (Non line of sight) conditions. It has a mobility up to 120 km/h and uses

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OFDMA (orthogonal frequency division multiple access) to achieve 75 Mbps of peak data rates in downlink [1].

1.2. LTE

It is expanded as Long Term Evolution. It is nothing but the upgradation of 3GPP technology aiming to provide high data rates. Based on the type of modulation and configuration of the antenna, data rates vary between 100 and 300 Mbps. It uses OFDMA in the downlink and SC-FDMA in the uplink. In OFDMA, different subcarriers with different frequencies send data for a long duration. But in SC-FDMA different subcarriers with different frequencies send the same data for a short period of time. Hence, the peak data rates of the uplink are greater than those of the downlink. Using SC-FDMA, the peak average power ratio [1] of the signal decreases, which helps in the increase in the battery life of mobile device. In both FDD and TDD, the bandwidth of carrier varies from 1.4 to 20 MHz. It handles a mobility of up to 250 km/h.

By considering the above advantages and disadvantages in Table 1, it is seen that the integration of LTE and Wimax will be effective among the available technologies. By integrating these two technologies, users can continuously get connected to any of the networks based on their availability, and attain high data rates. The benefits from the integration architecture depend upon the integrating points (type of interfacing) which are called as couplings. Each coupling has its own advantages and disadvantages. The different integration levels proposed in are open, loose, tight and very tight couplings. In these levels, we assume that the base stations serve mobile Wimax cells, and the enodeB serves LTE cells. But for the interworking protocol adaptation is necessary, since both networks work with different mechanisms [2]. So, a logical entity FAF is added along with ANDSF (Address network discovery and selection process) in the general interworking architecture [3]. With further developments in this, new architectures were proposed to provide IP multimedia services like voice, video and mail [4] services. An access technology independent interworking environment is provided by IMS, and SIP acts as a crucial part of it. The main advantage of IMS is, it reduces the VHO delay. This paper presents a cross layer architecture for a seamless vertical hand over. Later, it discusses the importance of the reduction of energy consumed by the device, and also the current research works like Mobile femtocells, cognitive radio networks, visible light communication, which aim to achieve high energy efficiency [5], seam less coverage, high mobility, high date rates and larger network capacity.

Table 1 Comparison between LTE and WIMAX.

Parameters	Wimax	LTE
Availability	$\gg$	$<$
Cost of migration	$<$	$\gg$
Peak data rates	$>$	$\gg$
Performance of uplink	$>$	$\gg$
Performance of downlink	$>$	$\gg$
Mobility	$>$	$\gg$
Provision of Qos	$\gg$	$\gg$
Power saved by UE	$>$	$\gg$

Table 2 Representation of delays involved during MIP registration.

Delay involved	Message
$dlsol_{(MS\text{-}BS)}$	Solicitation
$dladv_{(BS\text{-}MS)}$	Advertisement
$dlreg_{(MS\text{-}HA)}$	Registration
$dlrep_{(HA\text{-}MS)}$	Reply
$dlBi{:}U_{(MS\text{-}HA)}$	Binding update
$dlBi{:}U - ACK_{(Co:N\text{-}BS)}$	Acknowledgement for binding update

Table 3 Representation of delays involved during SIP registration.

Delay involved	Message
$dlok_{(MS\text{-}S:CSCF)}$	OK response
$dlreinvite_{(MS\text{-}CN)}$	Reinvite message
$dlok_{(CN\text{-}MS)}$	Ok response
$dlack_{(MS\text{-}Co:N)}$	Acknowledgement

Table 4 Values of various parameters used in simulation.

Message	Size (bytes)	Parameter	Value
Invite	737	K(WL)	0.002 sec
Re-invite	732	K(W)	0.0005 sec
Binding Acknowledgement	66	Ti(ad)	1 sec
200 Ok	572	DL(HSS)	1 ms
Binding Update	558	200 Ok	572
Acknowledgement	546	G(m)	10–100 pkts/sec
Registration request	314	G	10–100 pkts/sec
Registration reply	60	G(s)	10–100 pkts/sec
Bind.Update	56		

2. Comparison of couplings

The main requirements that are to be considered for the interworking architecture [2] are:

- Mobility support (Hand over between LTE/Wimax).
- Roaming agreements between both operators.
- Subscriber identification should be such that it can be used in both pure LTE/Wimax Networks.
- The subscriber data base (HSS/HLR) is shared among both networks; otherwise Separately for both networks.

Let us consider the integration architecture of UMTS and WLAN architecture to understand the role of couplings.

2.1. Loose coupling

Here, both networks work independently, and the data streams of each network are transmitted separately. But, both networks follow common authentication procedures by the interface link between the HLR of UMTS and AAA of WLAN [2]. A vertical handover is possible, but the servicing network has to be dropped before it connects to a new network. So, seamless handover is not possible in this coupling. The respective block diagram is shown as Fig. 1.

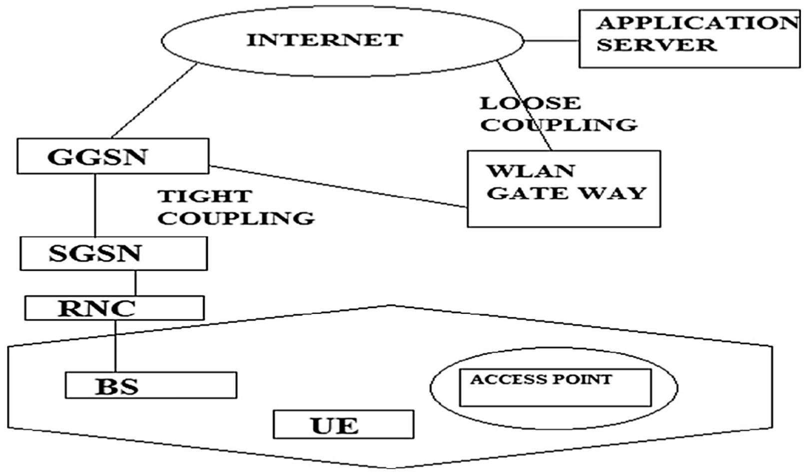

Figure 1 Loose and tight coupling.

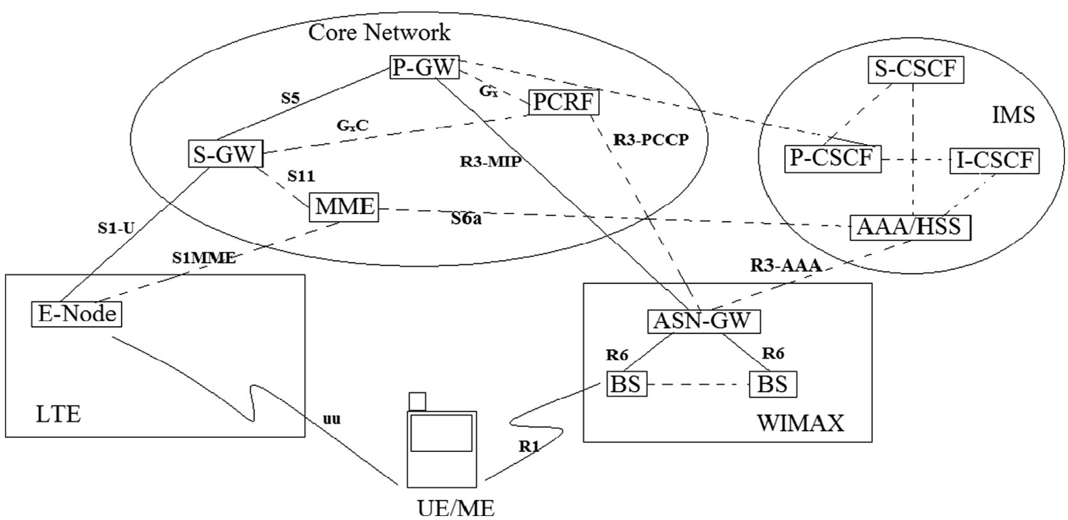

Figure 2 Proposed Wimax and LTE integration architectures.

2.2. Tight coupling

In this coupling, the WLAN gateway connects to the GGSN. So, the data streams of WLAN pass through the core network of UMTS, which results in signal overflow. It is able to perform seamless handover, fast handover decision [2,6] during and before the configuration. The respective block diagram is shown as Fig. 1. Vertical handover latency can further be reduced by using IMS along with the tight coupling. IMS provides multimedia services like voice over IP and voice mail. Keeping this in view, the Wimax and LTE integration architectures are proposed based on IMS. The respective block diagram is shown as Fig. 2.

3. Functional entities of core network of LTE

To lessen the radio frequency coexistence, seamless hand over must happen without relying on transmission from both the networks at the same time. Challenges arise due to the difference in their AAA authentication procedures, QOS mechanisms, mobility protocols. The major challenge is that the handover latency should not be more than milliseconds and communication experience must sustain. In IP based networks, mobility is handled by protocols reducing the need for signalling (RSSI). Signalling between routers reduces the delay to discover a new router. Also, depending on the strength of the signal and the requirements of QoS, the network is allowed to enable handover. The major issues involved practically [3] are translating messages among the two networks efficiently, initiation of the handover, appropriate implementation of hardware, exchange of signals and working efficiency. These exchanged signals contain control messages, which trigger handover. To reduce the complexity of mobile terminals, a single radio interface is used at a time.

For seamless hand over, the system has to be in a position to sum up different data in several languages into common language. For the initial network discovery, if we use RSSI (Radio signal scanning interface), the battery consumption is less, the discovered information is less and 2 receivers are needed to work in parallel [7]. To solve this issue [3], each cell must broadcast information about the neighbour cell, regardless of the Wimax and LTE cells. For this 2G and 3G cells are upgraded, such that the base station must provide measurement scheduling opportunities to a mobile device. To reduce the above impact of the radio system, it is better not to broadcast cell information. But the cell can better know it by special function ANDSF [3] which provides QoS and charging rates that are provided normally due to high demand.

3.1. S-GW

It is expanded as the serving gateway. IP packets are transferred by S-GW. For inter enode B handover it acts as a mobility handover. When user equipment is in the ideal state, information regarding the bearer is stored. The down link data is buffered temporarily in S-GW. In a visited network, it does some administrative works like collecting charging information [8].

3.2. MME

It is expanded as the mobility management entity. It is a control function entity. The inter node signal is provided by MME for mobility among 3GPP networks. It selects S-GW. It performs the roaming function, authentication and NAS signalling (Non Access Stratum). In simple words, it is a control function for mobility, authentication and security [9].

3.3. PCRF

It is expanded as the policy control and charging rules function. It acts as a control function for decision making among available policies. It controls the functional entity PCEF (which is present in packet gateway), which performs flow-based charging.

3.4. HSS

It is expanded as the home subscriber server. It holds information regarding the profile of the user like his QoS policies, specific PDN to which the user has to be connected, and the specific MME to which the user has already connected.

3.5. P-GW

It is expanded as the packet gate way. It filters the users packets (downlink IP) in to different QoS. For an interworking environment, it acts as a mobility anchor.

4. The IP multimedia subsystem

It is a 3 layer architecture, mainly initiated with the goal of providing multimedia services like voice mail, video call, over the internet. The architecture comprises of transport layer, where all functional entities of the access networks are included. The IMS core consists of the following functional entities [6].

4.1. AS

It is expanded as an application server. The server gets active by SIP and services are implemented as per the desire of user in the IMS network.

4.2. HSS

It is expanded as the home subscriber server. The users profile, policies of QoS are stored as a data base in HSS.

4.3. SIP

It is expanded as the Session Initiation Protocol. These severs are called the call session control function. The function of the CSCF is to start, manage and [3], release multimedia sessions with the appropriate QoS. CSCF are of three types.

P-CSCF: It is expanded as the Proxy CSCF. It is the first functional entity in the IMS which interacts with the signal [10]. So, first it checks the authentication of the user and then verifies the SIP requests.

I-CSCF: It is expanded as the Interrogation Call State Control Function. It interrogates the users identity and gets information regarding the destination of the SIP terminal location by communicating with the HSS.

S-CSCF: It is expanded as the Serving Call State Control Function [8]. The registration of the user, session management handling and Sending SIP messages to their respective nodes are the functions of the S-CSCF.

5. Cross layer vertical handover

A development in interworking architecture is to provide seam-less handover and support QoS by integrating the MIP and SIP protocols. In the proposed cross layer architecture as shown in Fig. 2, EPC is the core network and IMS is the network to provide multimedia services and manage the sessions. It reduces seam-less vertical handover latency, signal overhead not only at the IMS network, but also at the user equipment. The serving gateway and the P-GW of the core network are connected to the LTE and Wimax respectively. An access technology independent interworking environment is provided by the IMS. The communication between the IMS and EPC is made by the p-cscf. The signal sent to the IMS first enters the P-CSCF, then the I-CSCF where the interrogation of the users location, identity is done, and then to the S-CSCF, which manages the sessions. Security, authentication and mobility are managed by the control function, MME. HSS/AAA is the users data base. So, to find the users profile and his correspondent QoS policies, the MME connects to the HSS, in case of LTE as the control function, and the ASN gateway connects to the HSS in case of Wimax as a control function. ASN also makes data signalling with P-GW to transport data. But, in the case of 3GPP the data and control signalling are separated between the MME and S-GW respectively. The current care of address of the mobile is registered in HA while moving to another access network. The network layer messages are converted to application layer messages by HA and vice versa in the case of S-CSCF. When MS send SIP request, first it is received by the P-CSCF in IMS. Then the P-CSCF sends it to the I-CSCF where interrogation about the identity and location of the user is done by communicating with the HSS, and the appropriate S-CSCF is then selected by the HSS [8]. After user registration in S-CSCF, it forwards the SIP messages to the corresponding node and handles session management. The amount of data received is controlled by reading the controlling QoS parameters information in the PCRF [11]. Here, the communication between the P-GW and the P-CSCF appears to be cross layer signalling due to which a seam-less vertical handover was achieved.

5.1. Cross layer vertical handover signalling

This is a mobile assisted handover [8]. The respective signalling is shown in Fig. 3 Let us assume that the mobile is in a Wimax network and later it is handed over to LTE network. Usually E-Node B of LTE broadcasts agent .advert messages. In a dual radio interface by MS, one interface is for data transmission with a respective node in Wimax and the other interface is to detect the agent. advert messages. The broadcast of agent .advert messages can be enabled by agent .solicit messages. The Mobile station detects agent .advert messages, and the decision is made to switch over to LTE. Then, the MS makes the LTE link layer registration. Then, the registration allows the LTE to authenticate the user for the sending and reception of data. Besides this, the network saves the movement of the mobile. Then, a Regi.Req is given to P-GW by MS for MIP and IMS registration. In addition to the care of address of the mobile station, information regarding the P-CSCF and S-CSCF also exists in Regi.Req. Then, the IMS registration is triggered by passing the Regi.Req message to the HA in the IMS network by PGW. Then, the address of mobile station is updated in the data base of the HA. Successful MIP registration is informed to the MS by sending Regi.Reply message from the HA. Then, binding update messages are sent to the CN by MS as soon as it receives the Regi.Reply. After receiving the Regi.Req, the HA gets information about the address of the P-CSCF and S-CSCF. Then, the SIP register request is created and sent to the specific S-CSCF. Now, the S-CSCF updates the mobile stations current location to the HSS by making registration with it using the diameter protocol. Now, the reception of the 200ok response is considered as a successful IMS registration [12]. Then, the change of session parameters is informed to the core network i.e. Wimax by sending the SIP Reinvite message. The Reinvite message comprises of the updated session parameters as per the capabilities of the LTE network with the same call ID and identifiers of Wimax.

Then, upon the reception of the reinvite by the core network, it sends an acknowledgement by 200ok. The Mobile station again sends a 200ok response to The core network as a final response for successful reception of the 200ok. Now, data flow between the mobile station and the LTE network start, while it still receives data from the Wimax. Upon the reception of the SIP Bye message by the core network, the Wimax interface with the mobile station is terminated by the core network [12], and a OK response is given. Hence, the vertical handover is completed [8].

6. Mathematical equations

6.1. VHO delay

Vertical handover latency is the duration in which MIP and SIP signals are transferred among the network components from the moment of discovery of target network to the

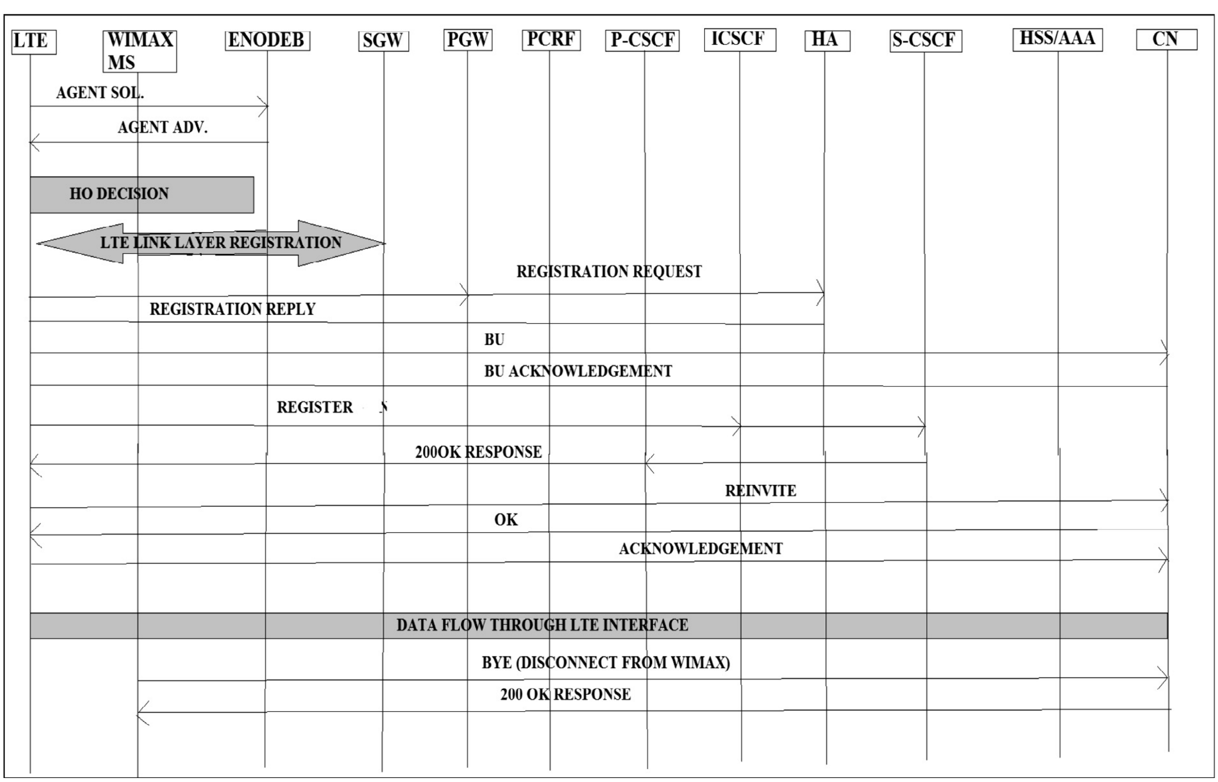

Figure 3 Cross layer vertical handover signalling.

moment of receiving acknowledgement from the core network. Besides, these take time to look up the HSS table that also contributes to the VHO delay [3]. Hence, the equation for the VHO delay is

$$DL(VHO) = DL(MIP) + DL(SIP) + DL(HSS) \tag{1}$$

Time taken to send a message of size S via wireless link having a bandwidth of $BW_{(WL)}$ is

$$\{(message\ size) * (time\ period\ of\ signal)\} = (SZ/B(WL)).$$

Usually the word signal delay comprises transmission delay, queuing delay, and processing delay. Transmission delay is being dominant compared to others here in the evaluation, hence, we consider transmission delay only. The following is the formula to calculate transmission delay (TR) provided with size of the message in bytes (SZ), number of hops message has to pass between a and b(Ka-b), bandwidth (BW) and latencies (K) for the wired (W) and wireless medium (WL) of the used network.

$$TR(SZ, Ka - b) = SZ/BW(WL) + K(WL) + K(a - b) * (SZ/BW(W) + K(W)) \tag{2}$$

MIP signalling delay is calculated by integrating transmission delays of all the messages involved as explained in previous chapters like agent solicitation, advertisements, registrations, reply, binding update and acknowledgement. Interestingly, cross layer and non cross layer scenarios have same MIP signalling delay. Hence, the equation for MIP signalling is (see Tables 2–4)

$$DL(MIP) = dlsol(MS - BS) + dladv(BS - MS) + dlreg(MS - HA) + dlrep(HA - MS) + dlBi.U(MS - HN) + dlBi.U - ACK(Co.N - BS) \tag{3}$$

SIP signalling delay is calculated by summing up the transmission delays of all the messages involved during IMS registration with HN and session reconfiguration with core network. Unlike MIP signalling delay here SIP signalling delay varies in cross and non cross layer scenarios. IMS registration in case of non cross layer scenario is handled by mobile station independently after MIP signalling whereas in case of cross layer scenario IMS registration is triggered by the MIP messages which results in zero interaction of SIP messages with the mobile station because of this number of hops passed through is reduced and there by delay is also reduced in case of cross layer scenario. Messages involved in SIP are registration, ok response, reinvite, acknowledgement. The following Eqs. (4) and (5) are used for calculating SIP signalling delay in non cross layer and cross layer scenario.

$$DL(SIP) = dlregi(MS - S.CSCF) + dlok(S.CSCF - MS) + dlreinvite(MS - CN) + dlok(CN - MS) + dlack(MS - Co.N) \tag{4}$$

$$DL(SIP) = dlregi(HS - S.CSCF) + dlok(S.CSCF - HS) + dlreinvite(MS - CN) + dlok(CN - MS) + dlack(MS - Co.N) \tag{5}$$

6.2. Packet loss

Generally packets are lost during handovers and the amount of loss depends on agent advertisement signal (Ti(ad)), vertical handover delay (DL), downlink packet transmission rate (G) and Nm, the number of handoffs during a session Nm (average resident time/average call connection time is Nm) [13].

$$\text{Packet loss} = [(2 * \text{Ti}_{ad}) + \text{DL}] * \text{G} * \text{Nm} \tag{6}$$

6.3. Cost of signalling

Cost of signalling can be calculated with the following equation provided with size of message (SZ(i)), number of hops it passes on in the network (Ka-b) and the mobility rate during the session (U). In general case,

$$\text{Cost of signalling(i)} = \text{SZ(i)} * \text{Ka} - \text{b} * \text{U}$$

If G_m is average network mobility rate, Gs is average call (session) arrival rate, and $Sz_{invite\text{-}I}$ is the IMS invite message sequence and $Sz_{reinvite\text{-}I}$ is the IMS reinvite message sequences size then cost of signalling provided with number of hops (Ka-b) is [14]

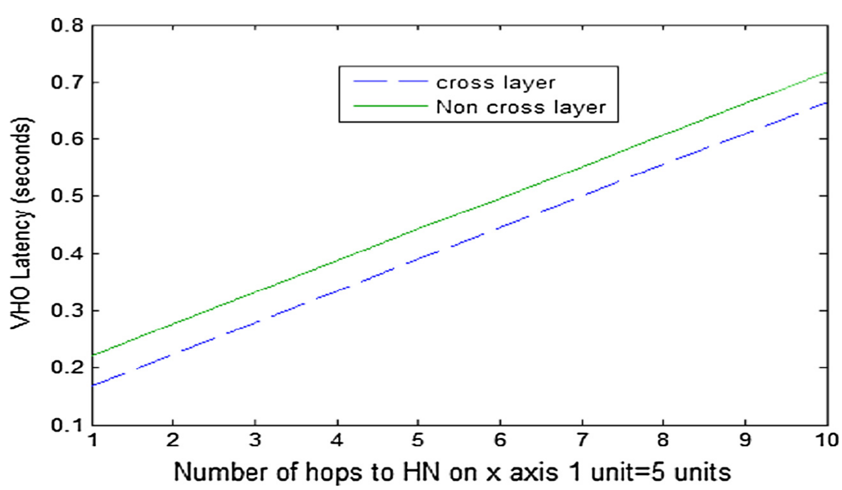

Figure 4 VHO Latency vs number of hops.

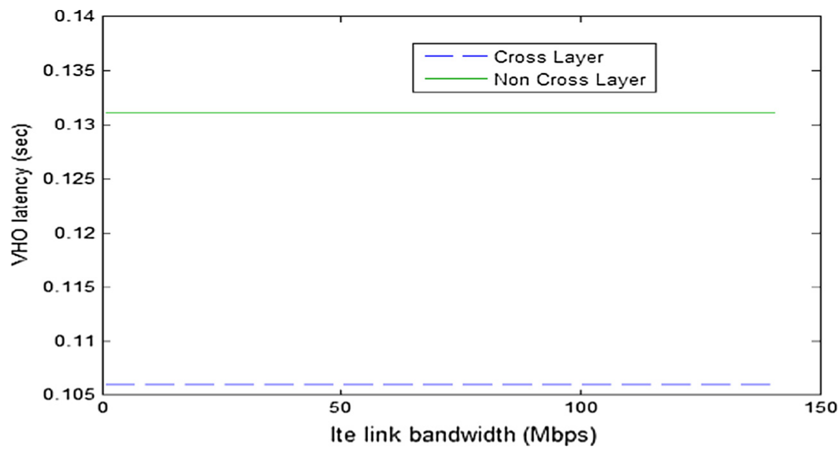

Figure 5 VHO Latency vs LTE link bandwidth.

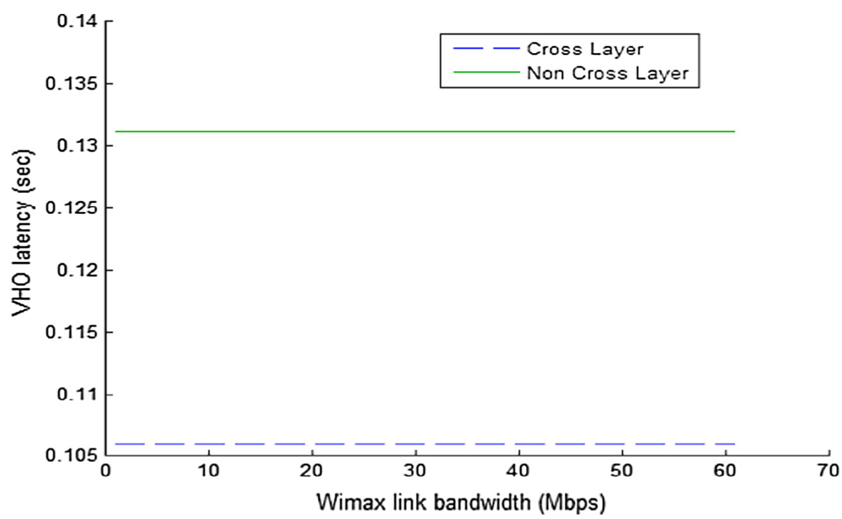

Figure 6 VHO latency vs Wimax link bandwidth.

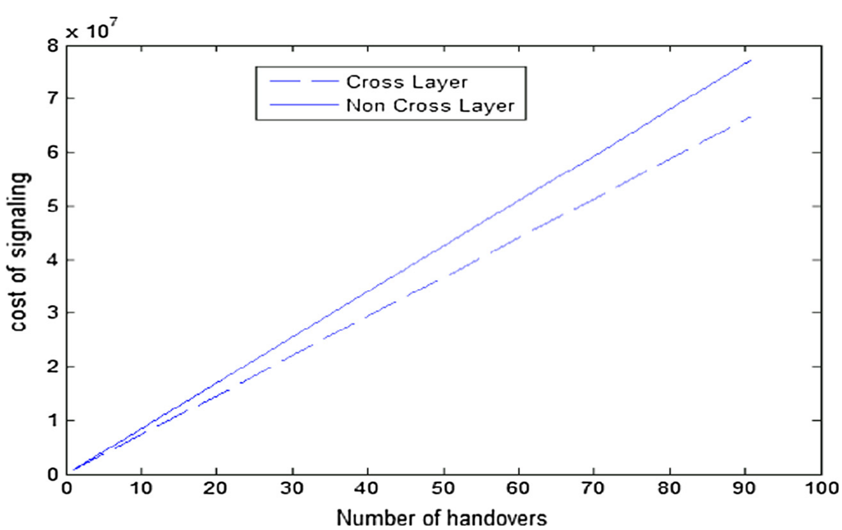

Figure 7 Cost of signalling vs number of handovers.

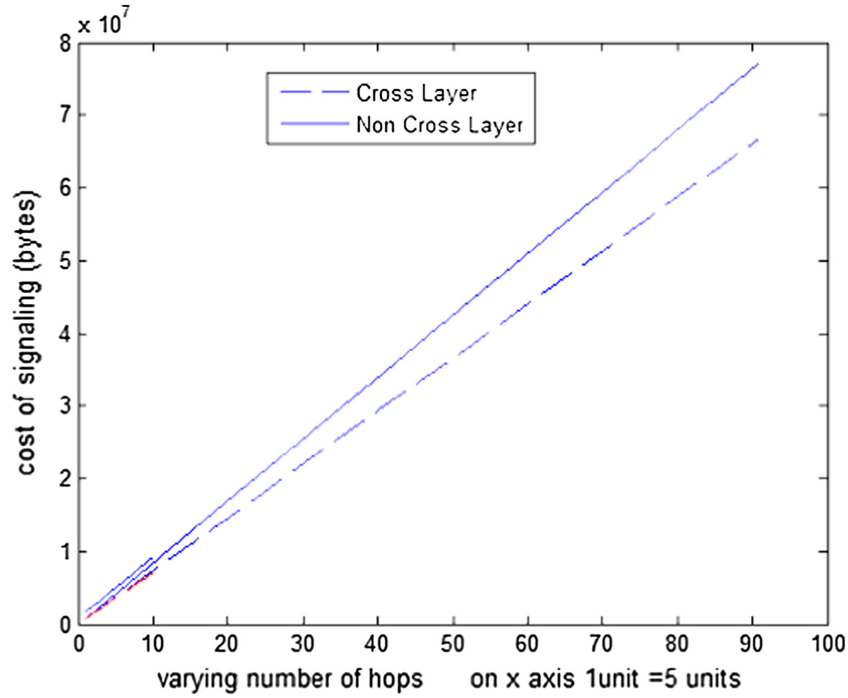

Figure 8 Signalling cost vs number of hops to HN.

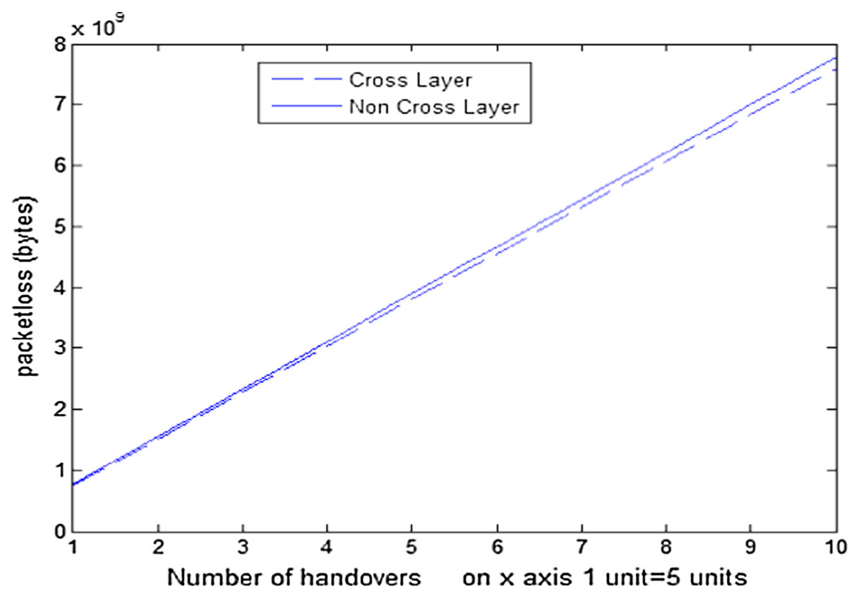

Figure 9 Packet loss vs number of handovers.

$$\text{Signal cost} = \left\{ G_s * \left[\sum (Sz_{\text{invite}-I}) * (k_{(a-b)}) \right] \right\} + \left\{ G_m * \left[\sum (Sz_{\text{reinvite}-I}) * (k_{(ab)}) \right] \right\} \quad (7)$$

7. Analysis of simulation results

With the obtained simulation results we inferred that increase in number of hops results in more transmission delay thereby more Vertical handover latency shown in Fig. 4, Fig. 10 shows packet loss and the effect is less in cross layer scenario as SIP messages are triggered by the MIP messages without the interaction of mobile station. In spite of this, cost of signalling is also less in cross layer scenario shown in Fig. 8. As number of handover increases number of packets lost, transferring delay, cost of signalling at each handover is added which results in more Vertical handover latency, packet loss shown in Fig. 9, cost of signalling and the effect is less in case of cross layer scenario due to the less handover latency shown in Fig. 7. From Figs. 5 and 6 we infer consistency of VHO delay even if

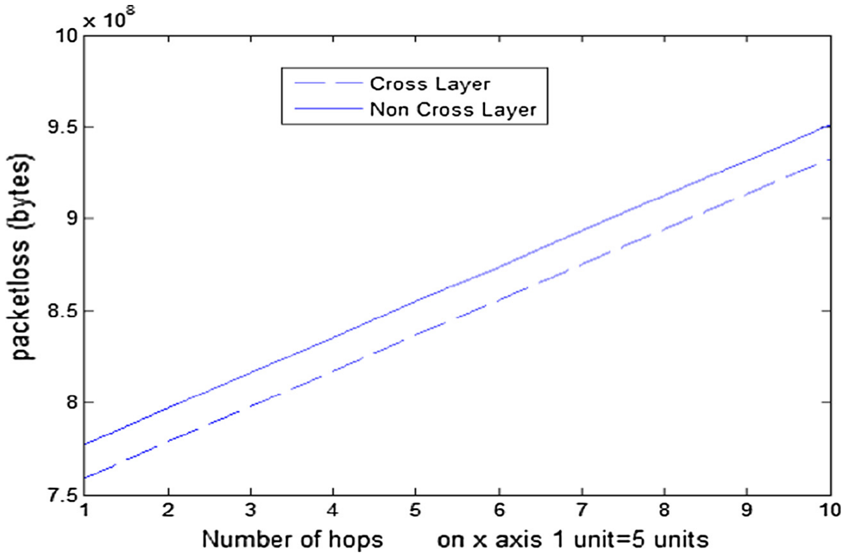

Figure 10 Packet loss vs number of hops.

the bandwidths of LTE and WIMAX were increased. Finally, these simulation results expose the impact in the usage of proposed cross layer architecture.

8. Conclusion

It can be concluded that the integration of LTE and Wimax provides online connectivity anytime and everywhere. By analysing the various simulation results obtained we can conclude that with the proposed architecture, handoff occurs with less delay, less packet loss, less cost of signalling, compared to the non cross layer scenario. As the data rates are high in both networks, the number of multimedia services received by the user tremendously increases year after year. By using femtocells in this architecture, there is an increase in the mobility supported, increased energy efficiency and increased battery life of user equipment.

9. Future works

As the days pass by, the number of objects (like smart phones, industrial machines, internet of things, etc.,) connected by a wireless interface is dramatically increasing. So, it is important to concentrate on the power consumption and reduce the energy consumed. The more the energy consumption, the more the emission of CO_2. This is indirectly a major threat to the environment [5]. Energy efficiency is the major challenge in green communication. LTE and Wimax use OFDM as the most spectral efficient technique, but consume more energy due to their high complexity and computational (analog, digital signal processing) intensity. Moreover, a recent survey reported that the energy consumed by a base station, contributes a 70 % of electricity bill to the vendors. Energy efficient communication is not the initial requirement of 4G. The challenges considered in 5G are high data rate, larger network capacity, high mobility, seam-less coverage and high energy efficiency. Among these 4G networks have just reached the theoretical limit on high data rates. So, they investigate 5G.

5G networks can get more system capacity and spectral efficiency than 3G and 4G technologies. They can provide a peak data rate of 10Gbps for low mobility and 1Gbps for high mobility. They can support communication in high speed trains that travel at a speed of 350 to 500 kmph. From this mobility aspect, 4G can support only up to 250 kmph.

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